DESIGN OF WATER LEVEL CONTROLLER USING FUZZY LOGIC SYSTEM

Thesis submitted in partial fulfilment of the requirements for the degree of

Bachelor of Technology (B. Tech) In

Mechanical Engineering

By

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Under the guidance of
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Certificate of approval

This is to certify that the project entitled, **"Design of Water Level Controller using Fuzzy Logic System"** being submitted by ***Mr. Harshdeep Singh*** has been carried out under my supervision in partial fulfilment of the requirements for the Degree of **Bachelors of Technology (B. Tech)** in Mechanical Engineering at National Institute of Technology Rourkela, and this work has not been submitted elsewhere before for any other academic degree/diploma.

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CONTENTS

ABSTRACT

Water level control is highly important in industrial applications such as boilers in nuclear power plants. In this work a simple water level indicator and a water level controller based on fuzzy logic is proposed. The fabricated electronic level indicator defines 2 levels minimum and maximum through LEDs. The fuzzy logic controller is based on Mamdani type Fuzzy Inference System. The fuzzy controller has two inputs, error in level and rate of change of error and one output, valve position. The fuzzy controller is implemented in MATLAB and then simulated in Simulink to test the behavior of the system when inputs change. The response of the fuzzy controller is then compared with a conventional PID controller. The results are shown sequentially and the effectiveness of the controller is illustrated.

CHAPTER 1

1. INTRODUCTION

In many industrial processes, control of liquid level is required. It was reported that about 25% of emergency shutdowns in the nuclear power plant are caused by poor control of the steam generator water level. Such shutdowns greatly decrease the plant availability and must be minimized. Water level control system is a very complex system, because of the nonlinearities and uncertainties of a system. Currently, constant gain PI controllers are used in nuclear organizations for boiler water level control at high power operations. However, at low power operations, PI controllers can not maintain water level properly. A need for performance improvement in existing water level regulators is therefore needed.

1.1 WATER TANK SYSTEM

In general, the flowing of water is supplied via a pump from a storage tank and water flow rate is adjusted with an actuator. Fig.1 shows the schematic of such a surge tank system.

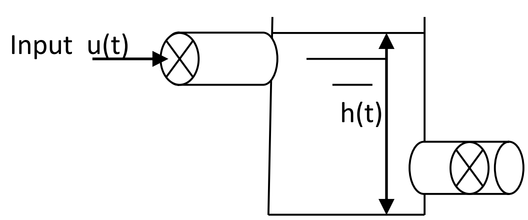


Fig.1 Surge tank system

The level of liquid is measured through a pressure transmitter. The transmitted pressure data is transferred to control circuit. The system model can be represented as a first order differential equation:

$$\frac{dh(t)}{dt} = -c\frac{\sqrt{2gh(t)}}{A} + \frac{1}{A}u(t) \tag{1.1}$$

Here, u(t) is the input flow (control input), which can be positive or negative that is it can both pull out the liquid from tank or put it in, h(t) is the liquid level (the output of the plant), A= $\sqrt{ah^2(t)+b}$ is the cross-sectional area of the tank, g=9.8 m/s^2 is acceleration due to gravity and c is known cross-sectional area of the output pipe.

There are various approaches to the design of the level controllers. The tank dynamics model based proportional integral derivative (PID) controllers have become famous for boiler level control. Advanced control methods such as linear quadratic Gaussian (LQG) based controller designs were also used earlier.

1.2 INTELLIGENT CONTROL METHODS

Conventional control approaches are not convenient to solve the complex issues in this highly nonlinear system. Neural networks and fuzzy logic control have emerged over the years and become one of the most active areas of research. There are many works in literature addressed the water level control issues using neural networks and fuzzy logic. Due to its simplicity, fuzzy logic control method became most famous in this application. Fuzzy logic is a form of probabilistic logic or many-valued logic; it deals with approximate reasoning rather than fixed and exact. Unlike traditional binary sets, where variables take either true or false values, fuzzy logic variables have a truth value that ranges in degree between 1 and 0. The truth value may range between completely true and completely false. Thus Fuzzy logic has been extended to handle the concept of partial truth. Fuzzy logic is a part of artificial intelligence or machine learning which interprets a human's actions. Computers can interpret only true or false values but a human being can reason the degree of truth or degree of falseness. Fuzzy models interpret the human actions and are also called intelligent systems.

A fuzzy set is an extension of a crisp set. Crisp sets allow only full membership or no membership at all, whereas fuzzy sets allow partial membership. In a crisp set, membership or non-membership of element x in set A is described by a characteristic function, where and. Fuzzy set theory extends this concept by defining partial membership. A fuzzy set 'A' on a universe of discourse U is characterized by a membership function that takes values in the interval. Fuzzy sets represent commonsense linguistic labels like slow, fast, small, large, heavy, low, medium, high, tall, etc. A given element can be a member of more than one fuzzy set at a time. A membership function is essentially a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. It provides a measure of the degree of similarity of elements in the universe of discourse 'U' to fuzzy set. Various types of membership functions are used, including triangular, trapezoidal, generalized bell shaped, Gaussian curves, polynomial curves, and sigmoid functions.

A fuzzy inference system (FIS) essentially defines a nonlinear mapping of the input data vector into a scalar output, using fuzzy rules. The mapping process involves input/output membership functions, FL operators, fuzzy if–then rules, aggregation of output sets, and defuzzification. An FIS with multiple outputs can be considered as a collection of independent multi-input, single-output systems. A general model of a fuzzy inference system (FIS) is shown in Figure 1. The FIS maps crisp inputs into crisp outputs. It can be seen from the figure that the FIS contains four components: the fuzzifier, inference engine, rule base, and defuzzifier. The rule base contains linguistic rules that are provided by experts. It is also possible to extract rules from numeric data. Once the rules have been established, the FIS can be viewed as a system that maps an input vector to an output vector. The fuzzifier maps input numbers into corresponding fuzzy memberships. This is required in order to activate rules that are in terms of linguistic variables. The fuzzifier takes input values and determines the degree to which they belong to each of the fuzzy sets via membership functions.

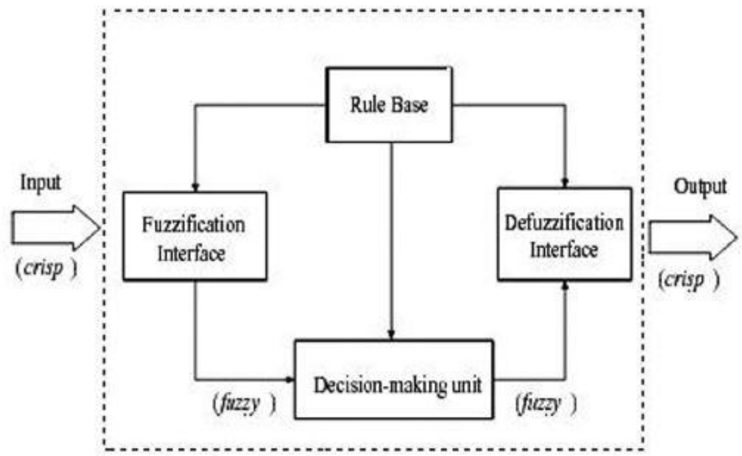


Fig.1.1 Fuzzy logic system

The inference engine defines mapping from input fuzzy sets into output fuzzy sets. It determines the degree to which the antecedent is satisfied for each rule. If the antecedent of a given rule has more than one clause, fuzzy operators are applied to obtain one number that represents the result of the antecedent for that rule. It is possible that one or more rules may fire at the same time. Outputs for all rules are then aggregated. During aggregation, fuzzy sets that represent the output of each rule are combined into a single fuzzy set. Fuzzy rules are fired in parallel, which is one of the important aspects of an FIS. In an FIS, the order in which rules are fired does not affect the output. The defuzzifier maps output fuzzy sets into a crisp number. Given a fuzzy set that encompasses a range of output values, the defuzzifier returns one number, thereby moving from a fuzzy set to a crisp number. Several methods for defuzzification are used in practice, including the centroid, maximum, mean of maxima, height, and modified height defuzzifier. The most popular defuzzification method is the centroid, which calculates and returns the center of gravity of the aggregated fuzzy set. Any system that uses Fuzzy mathematics may be viewed as Fuzzy system. Fuzzy systems can simultaneously handle the numerical data and linguistic knowledge.

1.2.1 TYPES OF FUZZY LOGIC SYSTEMS

There are two major types of control rules in fuzzy control:

1) Mamdani System – This method is widely accepted for capturing expert knowledge. It allows us to describe the expertise in more intuitive, more human-like manner. However, Mamdani-type FIS entails a substantial computational burden.
2) Takagi- Sugeno - This method is computationally efficient and works well with optimization and adaptive techniques, which makes it very attractive in control problems, particularly for dynamic non-linear systems. These adaptive techniques can be used to customize the membership functions so that fuzzy system best models the data.

The most fundamental difference between Mamdani-type FIS and Sugeno-type FIS is the way the crisp output is generated from the fuzzy inputs. While Mamdani-type FIS uses the technique of defuzzification of a fuzzy output, Sugeno-type FIS uses weighted average to compute the crisp output. The expressive power and interpretability of Mamdani output is lost in the Sugeno FIS since the consequents of the rules are not fuzzy [2]. But Sugeno has better processing time since the weighted average replace the time consuming defuzzification process. Due to the interpretable and intuitive nature of the rule base, Mamdani-type FIS is widely used in particular for decision support application. Other differences are that Mamdani FIS has output membership functions whereas Sugeno FIS has no output membership functions. Mamdani FIS is less flexible in system design in comparison to Sugeno FIS as latter can be integrated with ANFIS tool to optimize the outputs. Major benefits of fuzzy logic approach over the other methods are:

i) Fuzzy logic posses the ability to mimic the human mind to effectively employ modes of reasoning that is approximate rather than exact.

ii) Fuzzy Logic can model nonlinear functions of arbitrary complexity to a desired degree of accuracy.

iii) Perform better than the conventional PID controllers.

iv) Fuzzy Logic is a convenient way to map an input space to an output space. Fuzzy Logic is one of the tools used to model a multi-input, multi-output system.

v) It is simple to design and implement.

The fuzzy logic controller (FLC) acts as a part of the control system just like in conventional control systems. Fig.1.2 shows the FLC system with system described in state-space form.

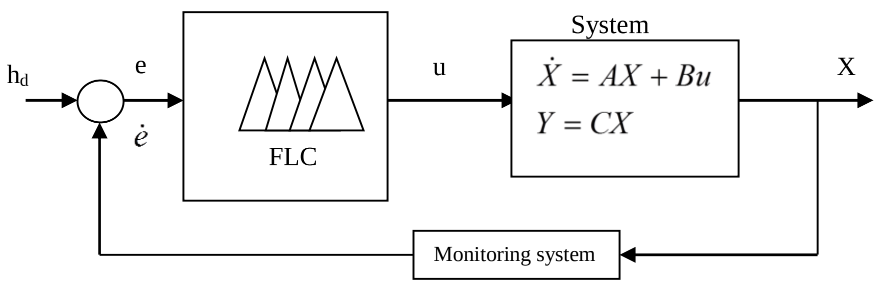


Fig.1.2 FLC control system

1.3 OBJECTIVES OF THE PRESENT WORK

Based on available literature, it is planned to develop a mechatronic model that can monitor the water levels and controls the inflow rate by properly positioning the valve at correct angles. Even though several such strategies are available, the simulations and practical implementation makes the project somewhat user friendly. For simulations, it is planned to use fuzzy logic control which makes use of Mamdani inference rule base (linguistic) consisting of 5 basic rules and the process has to meet the desired water level. The simulation results of conventional PID controller which makes use of the water level system model are used to show the effectiveness of the fuzzy logic controller. The organization of the thesis is as follows: chapter-2 explains the literature review of this work; chapter-3 deals with the methodology adopted which includes, basic electronic circuit for monitoring water levels and simulation procedure for implementation of fuzzy logic controller. Chapter-4 shows the output results of simulations and discussions. Finally important conclusions and scope for future work have been cited in chapter-5.

CHAPTER 2

2. LITERATURE SURVEY

This chapter presents a brief review of earlier works done in liquid level control strategies and various intelligent control techniques.

2.1 LIQUID LEVEL MONITORING AND CONTROL

Many earlier works dealt with various techniques of monitoring and controlling of liquid levels in industrial and domestic applications. Broadly this automatic control problem can be achieved under two means: mechanical methods and electrical methods. Float ball type liquid level control is a popular method of control still used in practice for normal applications such as overhead tank overflow restrictors etc. The electrical methods of control include a microcontroller-based circuits which automatically predict the liquid levels and accordingly active the circuit to operate motors. In spite of several such available methods, still there are new techniques in this application so as avoid dangerous operating conditions in industrial boilers.

Tan [1] proposed a water level control system for nuclear steam generator. The control system consisted of a feedback controller and a feedforward controller. The robustness and performance of both the controllers are analysed and tuning of the 2 parameter of the controllers. It is shown that the proposed gain scheduled controller can achieve good performance at high and low power levels.

Safarzadeh *et al*. [2] presented a water level control system for horizontal steam generators using the quantitative feedback theory.

Moradi *et al.* [3] proposed a control strategy to achieve desired tracking of drum water level. Sliding mode & H-∞ control schemes are employed. Transfer function between drum water level (output) and feedwater vs. steam mass rate were considered.

Maffezoni [4] highlighted the principal dynamic phenomena which determine the structuring of boiler-turbine control systems, clarifying the essential connections of such phenomena with the physical nature of the process. Zhang and Hu [5] proposed the water level control system using PI controllers. Zhang *et al.* [6] analysed the water level control of pressurized water reactor nuclear power station using PID and fuzzy controllers. Ansarifar *et al.*[7] proposed an adaptive estimator based dynamic sliding mode control method for water level control. Liu *et al.* [8] presented a proportional controller with partial feed forward compensation and decoupling control for the steam generator water level.

2.2 INTELLIGENT CONTROL TECHNIQUES

In 1965, the concept of Fuzzy Logic was conceived by Prof. Lotfi Zadeh at the University of California at Berkley. He presented fuzzy set theory not as a control methodology, but as a way of processing data by allowing partial set membership rather than crisp set membership or non-membership. This approach to set theory was not applied to control systems until the 70's due to insufficient small-computer capability prior to that time. Professor Zadeh reasoned that people do not require precise, numerical information input, and yet they are capable of highly adaptive control. If feedback controllers could be programmed to accept noisy, imprecise input, they would be much more effective and perhaps easier to implement [9]. Likewise, neural networks are also capable of representing the precise information from existing data sets. These intelligent control techniques like neural networks, fuzzy logic and genetic algorithms have been used in liquid level control for the last two decades.

In 1997, Park and Seong [10] investigated self-organizing fuzzy logic controller for water level control of steam generators. Wu *et al.* [11] built a prototype of water level control system implementing both fuzzy logic and neural network control algorithm and embedded the control algorithms into a standalone DSP-based micro controller and compared their performances. Sugeno model was used for fuzzy logic control system and Model Reference Adaptive neural Network Control based on back propagation algorithm was applied in neural network. Galzina *et al.* [12] presented applied fuzzy logic for water level control in boiler drum and combustion quality control. Fuzzy control rules were extracted from operator knowledge based on relative ruling criteria for existing boiler room. Taoyan *et al.* [13] proposed a novel interval type-2 fuzzy control system by extending the membership functions to interval type-2 membership function without increasing the design complexity. The control system can efficiently reduce the uncertain disturbances from real environment. Recently, Shome and Ashok [14] described an intelligent controller using fuzzy logic to meet the nonlinearity of the system for accurate control of the boiler steam temperature and water level.

CHAPTER 3

3. LEVEL INDICATOR AND FUZZY LOGIC CONTROLLER

This chapter deals with the proposed methodology of water level indication and the design of a fuzzy logic based controller.

3.1 PROPOSED WATER LEVEL INDICATOR

There are several types of water level indicators available. However, the electrical sensing devices are more reliable and easy to fabricate and install. For example, Reza et al. [15] proposed a water level monitoring and management within the context of electrical conductivity of water. They used a microcontroller based water level sensing and controlling a wired and wireless environment. Motivated from the past electronic circuits and with some available elements, a water level indicator which indicates low and high levels in a tank has been started as a beginning of this work. Fig.3.1 shows the electronic circuit diagram implemented.

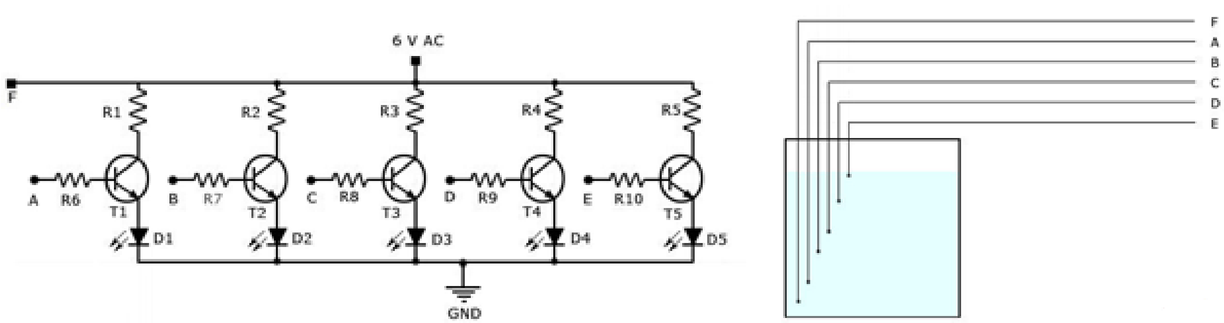


Fig.3.1 Electronic circuit based water Level Indicator

The level of any conductive non corrosive liquids can be measured using this circuit. The circuit is based on 5 transistor switches. Each transistor is switched on to drive the corresponding LED , when its base is supplied with current through the water through the electrode probes.

One electrode probe is (F) with 6V AC is placed at the bottom of tank. Next probes are placed step by step above the bottom probe. When water is rising, the base of each transistor gets electrical connection to 6V AC through water and the corresponding probe, which in turn makes the transistors conduct to glow LED and indicate the level of water. The ends of probes are connected to corresponding points in the circuit as shown in circuit diagram. The probes are arranged in order on a PVC pipe according to the depth in the tank. AC voltage is use to prevent electrolysis at the probes. The following electronic components are used:

(i) BC 548 Transistors (T1-T5)

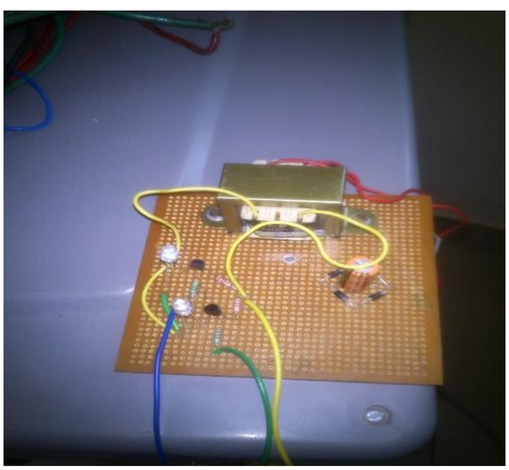
(ii) 2.2K 1/4 W Resistors (R1-R5)

(iii) 22K 1/4 W Resistors (R6-R10)

(iv) LED’s (D1-D5)

(v) transformer with 6V 500 mA

Fig.3.2 shows the photograph of the model implemented.



(a) Transistor based AC circuit

(b) Plastic tube with metallic plates at various levels

Fig.3.2

3.2 SIMULATION WITH FUZZY LOGIC CONTROLLER

The controller in present work is a Mamdani based one. It uses a rule base in linguistic terms. There are two inputs : error in liquid level $e(t)=h(t)-h_d$ and rate of change of liquid level $\dot{e}(t) = \dot{h}(t)$ and one output parameter: the inlet valve control angle u(t). Triangular membership functions are selected to fuzzify the inputs and output variables. There are set fuzzy sets taken (N, O and P) for each of the two inputs and five fuzzy sets for the output variable u. The ranges of the error and its time derivative (inputs) are set as follows:

$$e \in [-1, +1] \text{ and } \dot{e}(t) \in [-0.1, +0.1]\ ,\ u(t) \in [-1, +1]$$

Figure 3.3 (a) – (c) shows the fuzzification process with y-axis as membership values.

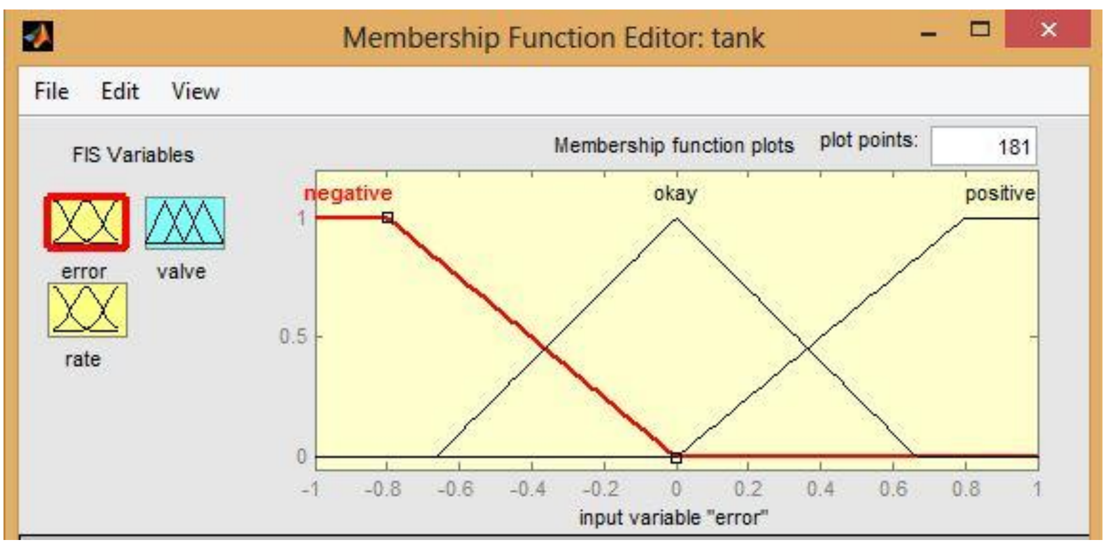


Fig. 3.3 (a) Fuzzification of error e(t)

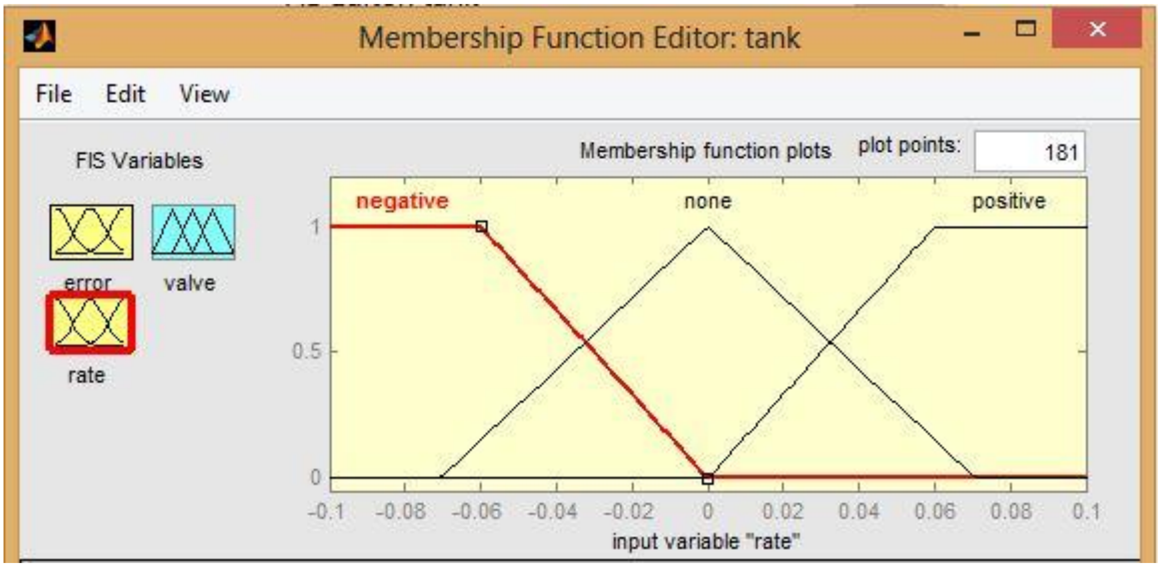


Fig. 3.3 (b) Fuzzification of rate of error

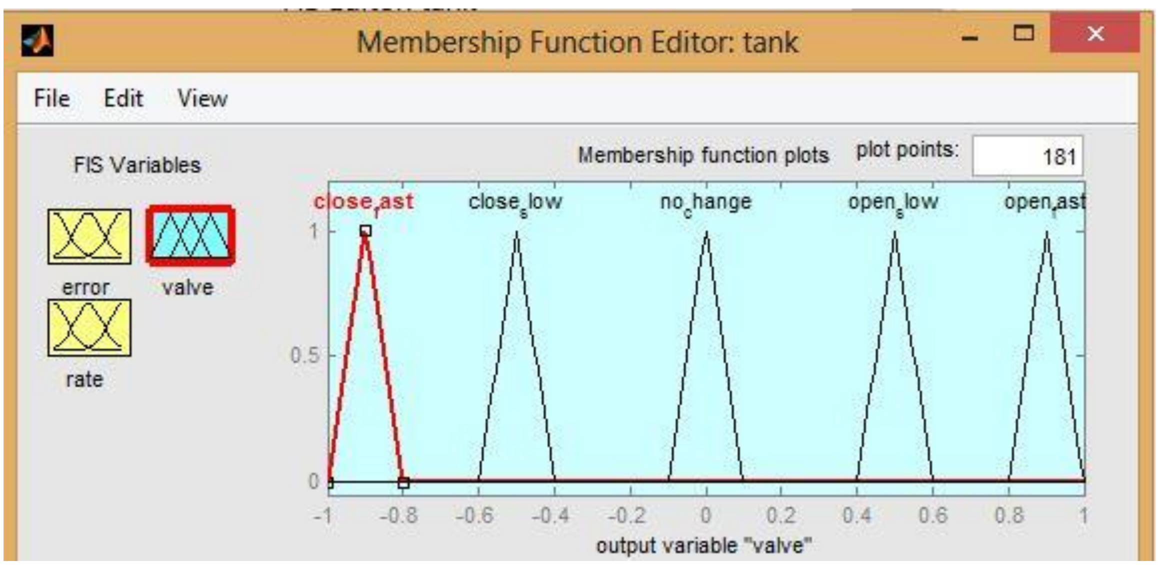


Fig 3.3 (c) Fuzzification of Input flow u(t)

After fuzzification, as a next step a rule base will be created. Following five rules are used to make up the rule base:

Rule 1: If error is okay then valve is no_change

Rule 2: If error is positive then valve is open_fast

Rule 3: If error is negative then valve is close_fast

Rule 4: If error is okay and rate is positive then valve is close_slow

Rule 5: If error is okay and rate is negative then valve is close_fast

Fig.3.4 shows the corresponding rule editor window in MATLAB fuzzy logic toolbox.

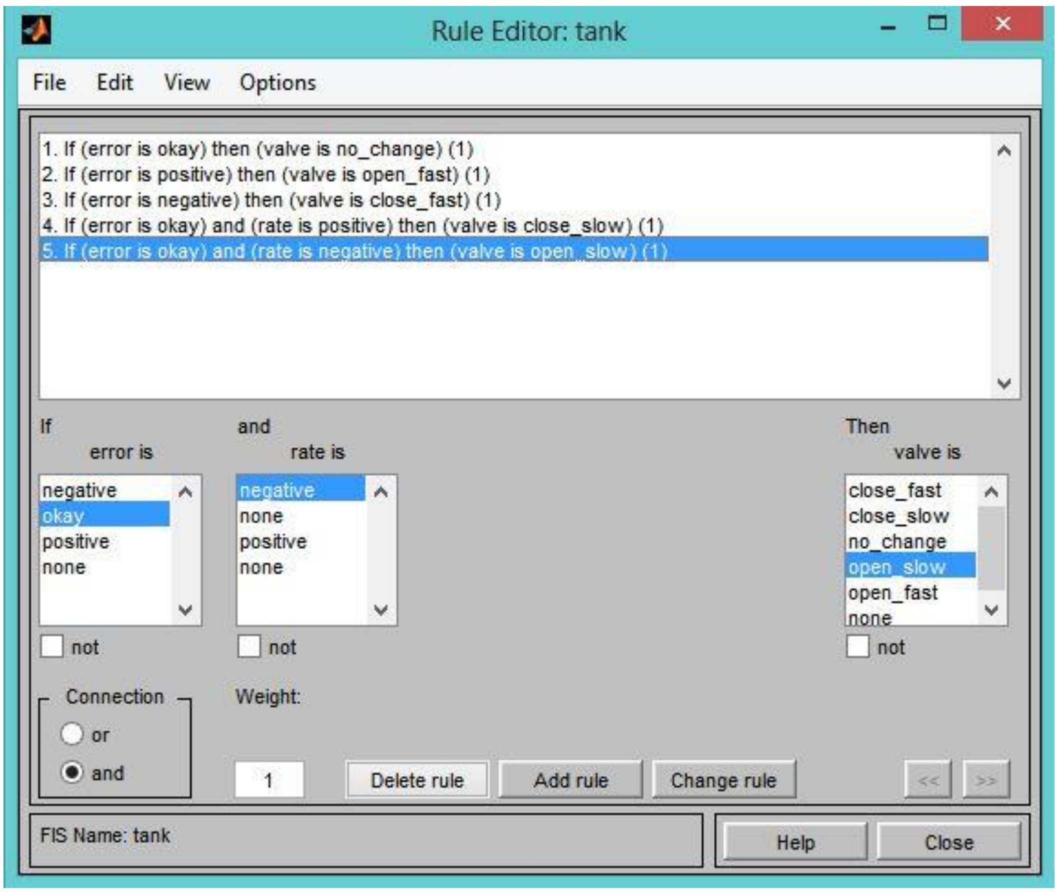


Fig 3.4 Rule Base considered

After the design of FLC, it is tested with a few examples. The defuzzification uses centroidal or centre of gravity scheme. Fig 3.5 shows the Simulink block diagram of the fuzzy logic controller and PID controller. The fuzzy inference system was implemented in this fuzzy logic controller and simulated to get the response of the controller to the given parameters.

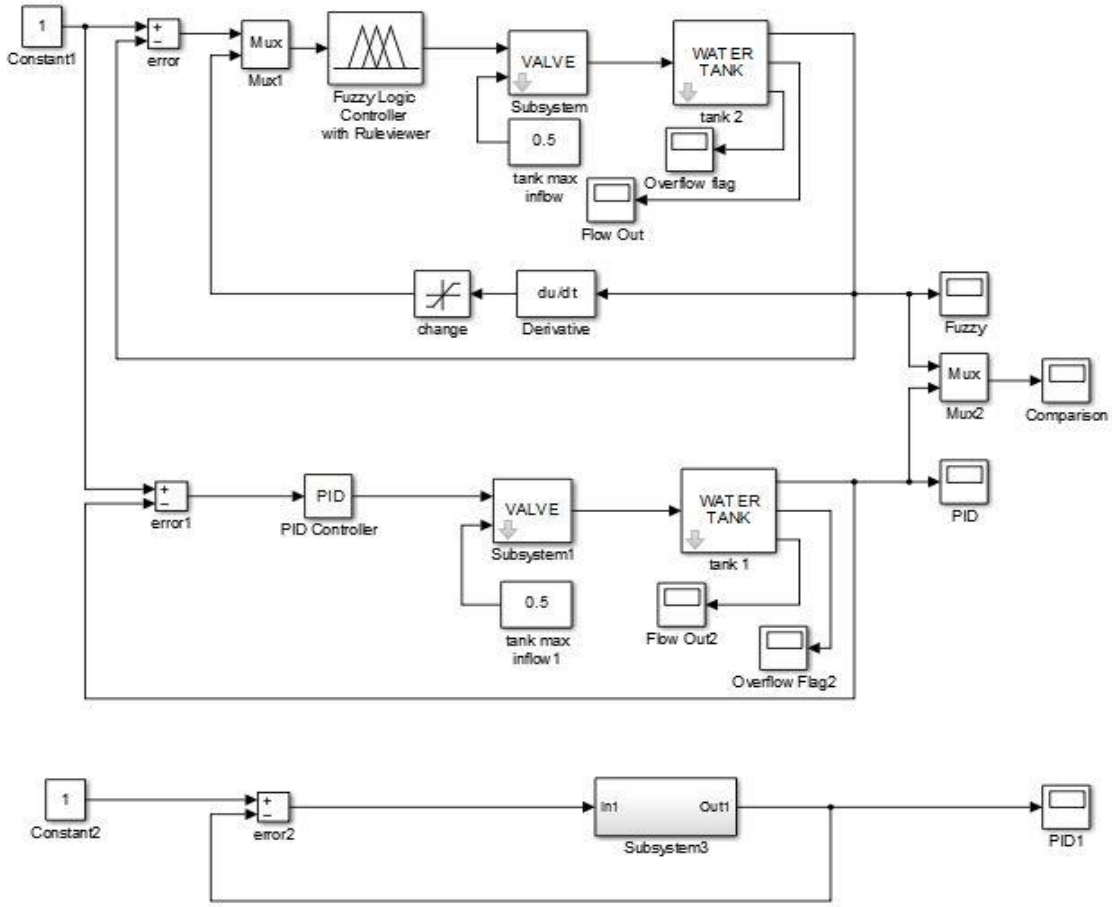


Fig 3.5 Simulink block diagram

Fig 3.6 shows the Simulink block diagram for water tank sub system shown under Fig 3.5.

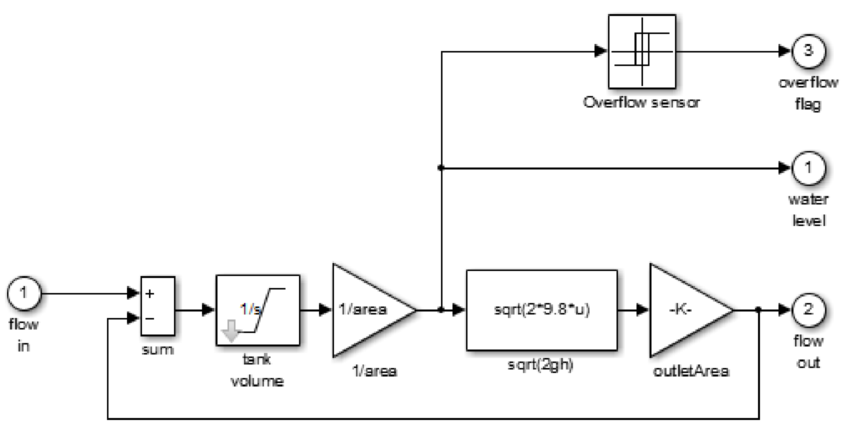


Fig 3.6 Water tank system

CHAPTER 4

4. RESULTS AND DISCUSSIONS

This chapter presents the simulation results of fuzzy logic controller for liquid levels.

4.1 DEVELOPMENT OF FUZZY LOGIC CONTROLLER

Two input and one output system is simulated with fuzzy logic toolbox in MATLAB. As explained in chapter 3, three fuzzy levels are considered for each of the two inputs and five levels for the output parameter. Rule base consisting of five rules will be activated to follow-up the desired liquid level. The rule viewer is used to get the crisp defuzzified values for the corresponding crisp inputs given. It shows the fuzzification and defuzzification process. The result is shown as the red line in the output (Fig.4.1).

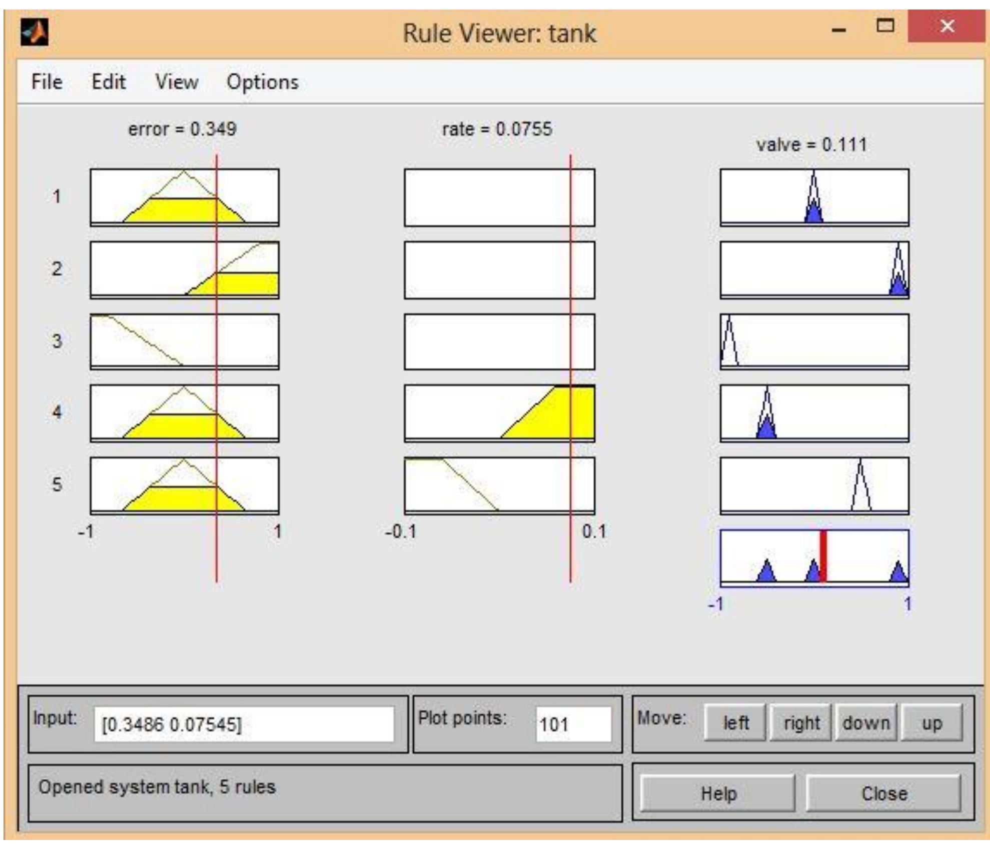


Fig 4.1 Rule Viewer

Fig.4.2 shows the surface viewer indicating 3 D graphical realization of the fuzzy rule base.

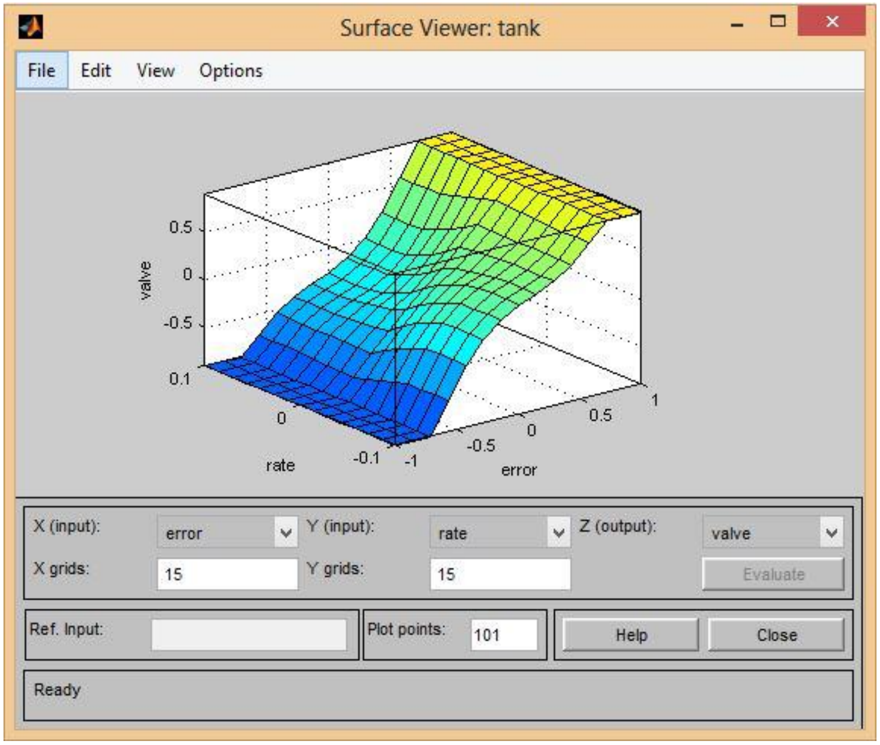


Fig 4.2 Surface Viewer

Fig 4.3 shows the response of fuzzy controller on simulation. The controller stablizes at the desired water level very quickly.

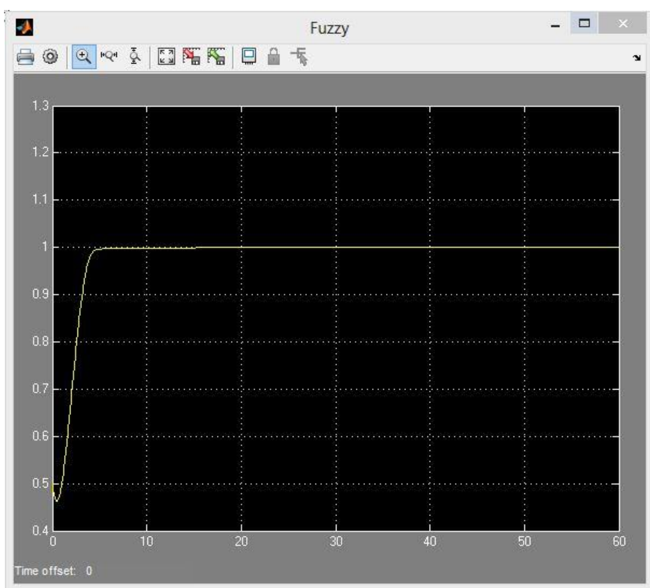


Fig 4.3 Fuzzy controller response

But the controller takes time to respond for a few seconds so the water level plunges. Fig 4.4 shows the input data considered for water tank system.

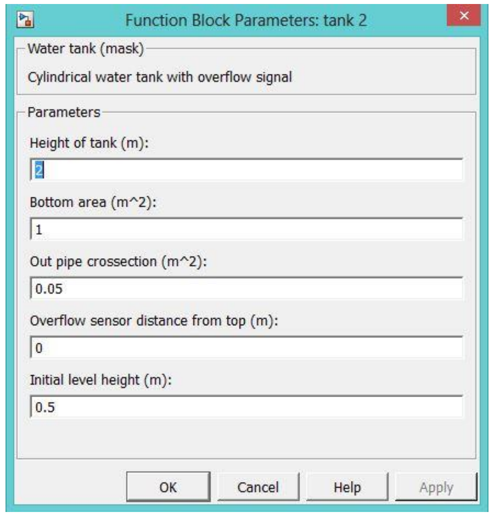


Fig 4.4 Input parameters for the system

4.2 PID CONTROL SCHEME

Fig 4.5 shows the response of the PID controller when simulated with the given parameters. The graph shows that the controller has an overshoot and takes time to stabilize to the desired value of 1m.

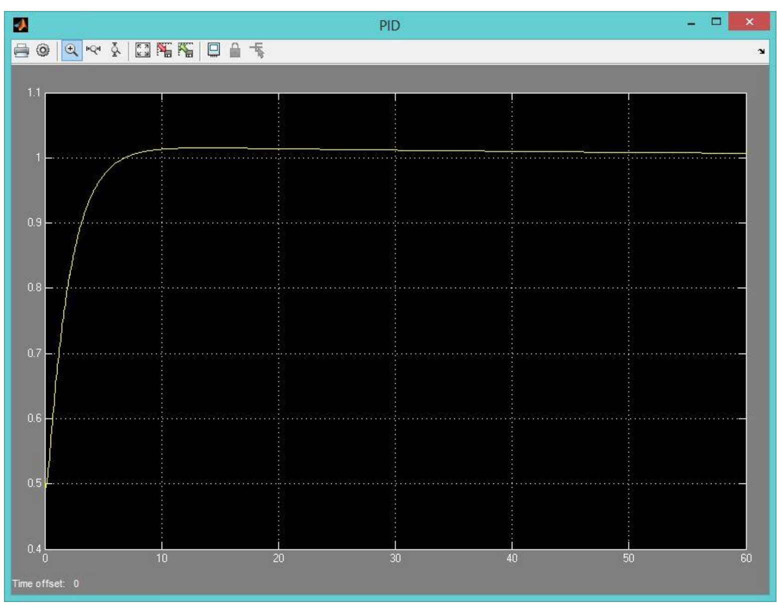


Fig 4.5 PID response

Fig 4.6 shows the comparison of fuzzy and PID controller transient response for 1m desired level (pink line shows PID and yellow one indicates fuzzy). It is clear from the graph that the PID controller has a large overshoot compared to the fuzzy controller and also takes a lot of time to stabilize at the desired level. Fuzzy logic on the other hand, has little overshoot and steady state error and stabilizes quickly providing accurate level control. We find that the advantages and disadvantages of PID control and fizzy control just offset each other. We can use fuzzy controller for rapid control (coarse adjustment) and then use PID controller for accurate control (fine tune).

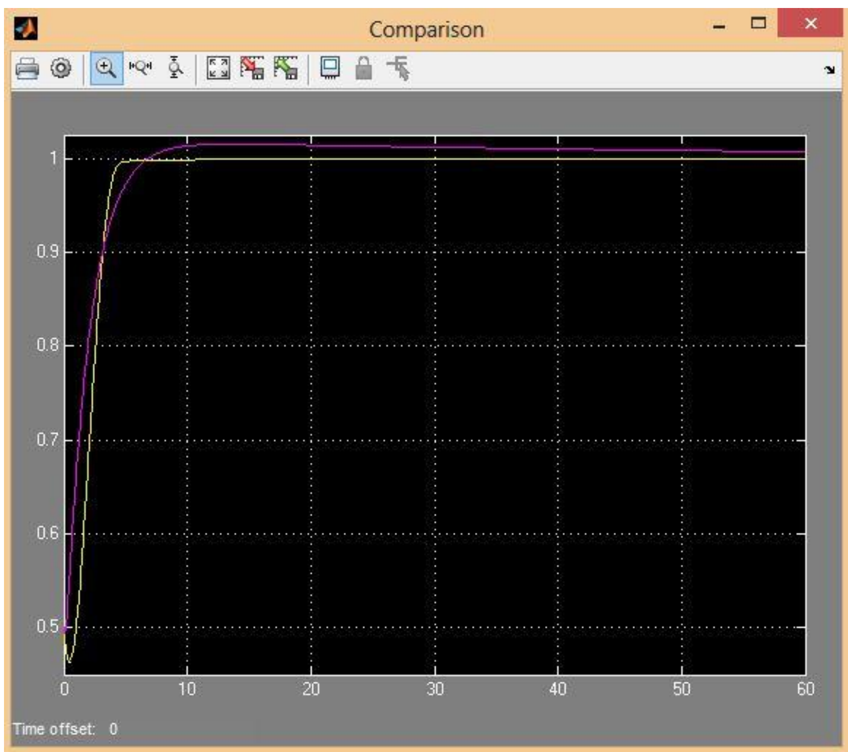


Fig 4.6 Transient Response of Fuzzy and PID controllers

As seen from the figure, compared with PID control program, the overshoot δ is less in fuzzy curve. Settling time reduces. The result of the simulation shows that as far as no balance and complex mathematical models, such a fuzzy control is similar to the human way of thinking. And it is suitable for coarse control at the beginning of the operation to rapidly control. And in order to get better control accuracy, PID control program used as a fine tune. On the other hand, the fuzzy and PID control program presented has a wide practical value because of the fuzzy control program does not rely on the mathematical model. It can be tried with a fuzzy controller which generates the rule base based on the PID scheme. An optimized FLC by tuning the fuzzy parameters may be employed to get the better accuracy.

5. CONCLUSIONS

The water level indicator is built and is tested to be working properly. Based on the existing MATLAB fuzzy logic toolbox demo, the controller is implemented and simulated successfully and the results are promising and satisfactory. This unconventional control approach can be used in boiler water level and also temperature control applications of nuclear/thermal power plants. As a future scope of this work the FLC can be implemented in a microcontroller with additional set of rules for more accurate control and can be used in various applications in industry and household. The controller can also be tested with periodically varying liquid level tracking applications.

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